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Static analysis of the supporting structure of steel hall racks using the BIM model

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ABSTRACT:
The static and strength analysis of three variants of the supporting structure of storage hall racks using BIM modeling was presented in the work. Based on the structure model, three variants were adopted, the static diagrams of which were presented in the paper and subjected to the same loads. A comparative criterion was proposed, based on which the most advantageous variant from the point of view of the structure's operation was selected. The BIM model information exchange was carried out using the IFC format. The analysis of the results and conclusions were included in the paper.

KEYWORDS:
BIM model; IFC; steel structure; static analysis

1. Introduction

According to BIM technology, intelligent design is appropriate, with the most accurate implementation of project data, especially before starting the design of the structure itself. Effective modeling consists first in gathering all information about the object (geometric and non-geometric) in the model, so that all project participants can access the information they are looking for without involving the entire team [1]. Before starting the first design activities, it is necessary to decide what tools will be used and to what extent and at what level. This has a direct impact on the complexity of the project and its execution time, and consequently on the use of the BIM model [2]. The study presented in [3] involves the modeling software ArchiCAD, Revit, and AECOsim and the structure analyzes tools SAP, Robot, and ETABS. The transfer processes were realized in two ways: using the native data format and using the Industry Foundation Classes (IFC) format. The study came to the conclusion, throughout the development of several building cases, that the methodology has clear advantages in the development of the structure project.

The current status and issues of the structural design processes with benefits of BIM were disscussed in [4]. In order to test and understand the possibilities that the BIM methodology offers, authors of work [5] presented the real benefits of its use. Before starting work, the scope of the project must be determined and the substrate must be prepared. This is a very important stage and the smoothness and quality of further work depends on it. The document containing this information is referred to as the Employers Information Requirements (EIR) [6]. The developed concept avoids the use of separate models for certain purposes and prevents the creation of useless information [7]. Once all the assumptions are in place, a design environment for operation can begin to be created. The choice of software will depend on the method of 3D modeling, displaying information contained in the CAD/BIM files, displaying information contained in the

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IFC and adding and editing information contained in the IFC [8]. Depending on the industry in which the organization operates, other tools will be used. Industry Foundation Classes, referred to as IFC, is an international, open standard specified in [9], which is compatible with many devices and neutral for both designers and contractors. The IFC model can be used throughout the entire life cycle of a building, from the design phase, through data exchange between different disciplines (such as architecture, structures, HVAC), to facility management.

The BIM standard is a set of methods, innovative solutions and regulations developed by practitioners, aimed at optimizing and accelerating processes throughout the entire life cycle of a facility. The advantages of using the BIM in the construction sector was included in [10]. General information about BIM in construction was included in [11]. An investigation into the extent to which emerging building information modelling (BIM) can be applied to construction logistics management is presented in [12]. Tasks involving the selection of the most effectively cooperative elements in building structures are the main goal and design idea. The process of dimensioning elements is carried out as a result of adopting the architecture of the object, regardless of the purpose of the work. The latest achievements concern solutions using modern methods and design tools to improve the work of people involved in the project. The work [13] describes, in detail, topics with distinct use of BIM, especially generation and use of a 4D/BIM model to support construction planning and coordination of the construction project based on BIM methodology. In the [14] the research work were indicated gaps in the research and important areas for future research include modeling of structural components, automation of the assembly sequence, planning and optimization of off-site construction, and dynamic structural health monitoring using BIM models. In this work a solution for the selection of support systems for cold store racks with the use of BIM model was proposed.

2. Variants of construction solutions using the BIM model

The paper presents static and strength tests of the supporting structure elements of the cold store hall racks using a BIM model on the basis of regulations included in standards [9, 15]. The BIM model of the building architecture with dimensions: 23.4 m × 24.0 m × 43.5 m (width × length × height) was prepared in Revit. In this paper, Revit was used as a tool for modeling and integrating the construction industry with the architectural one. Three solutions of static schemes were adopted for the analysis, which were modeled in the BIM model. The schemes adopted for analysis are presented graphically in three variants in Figure 1.

a) b) c)

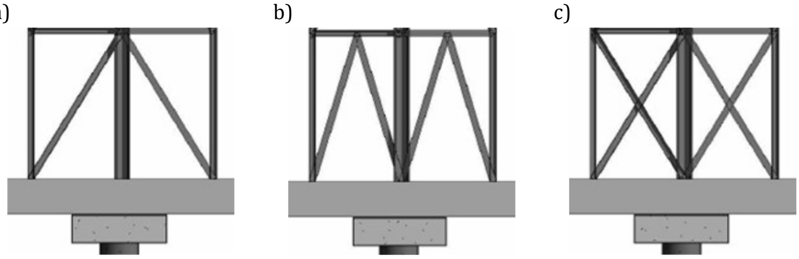

Fig. 1. Variants of structural solutions of supporting elements of the first level of the structure: a) type A, b) type M, c) type XX (own materials, using the Autodesk Revit program)

The supporting structure will fulfill two functions:

a) supporting the main structure in order to stiffen the structure and strengthen the columns by evenly distributing the operational loads;
b) limiting the space in the racks of the main structure, used for storing products in the facility.

The elements of such a set are designed with regard to uneven load distribution, additional loads transferred from the main structure and their own weight. Selecting the appropriate cross-sections is a key point in the design of such objects. The aim of the research is to select the structure that will be the most economically advantageous. The three proposed structural systems of the cold store rack bracing were analyzed based on permanent and variable loads, in accordance with design requirements and normative acts. Based on the BIM model, three sets of data were obtained in the form of values of reactions at support points and values of structure displacements. The paper proposes a criterion for selecting the bracing system as the ratio of displacement to reactions at support points. The discussed criterion is presented in formula (1).

$$K = \frac{\Delta x}{R} \cdot 100 \tag{1}$$

where:
K – comparative parameter [%],
Δx – maximum displacement [mm],
R – maximum reaction at support points [kN], $R = (|R_{max}|, |R_{min}|)$.

The criterion adopted in this way will be the basis for determining the most advantageous structural arrangement in terms of limiting the possibility of losing the stability of the structure, which is particularly important in the case of tall buildings.

3. Analysis of the concentration system and results from the program

The tests were carried out based on the same assumptions in all three variants. Cross-sections used to build the racks: columns made of cold-formed C-section 40 mm × 58 mm made of 2 mm sheet metal, beams made of cold-formed C-section 200×100 made of 2 mm sheet metal. In each variant, braces with a D30 tubular cross-section were assumed. Loads were applied in the structure nodes in the form of concentrated forces of 10 kN (vertical) and 5 kN (horizontal, in the plane of the braces). Analysis of the structural solutions was carried out using Advance Design software. The displacements of the structure as a result of the adopted support systems are shown in Figure 2.

a) b) c)

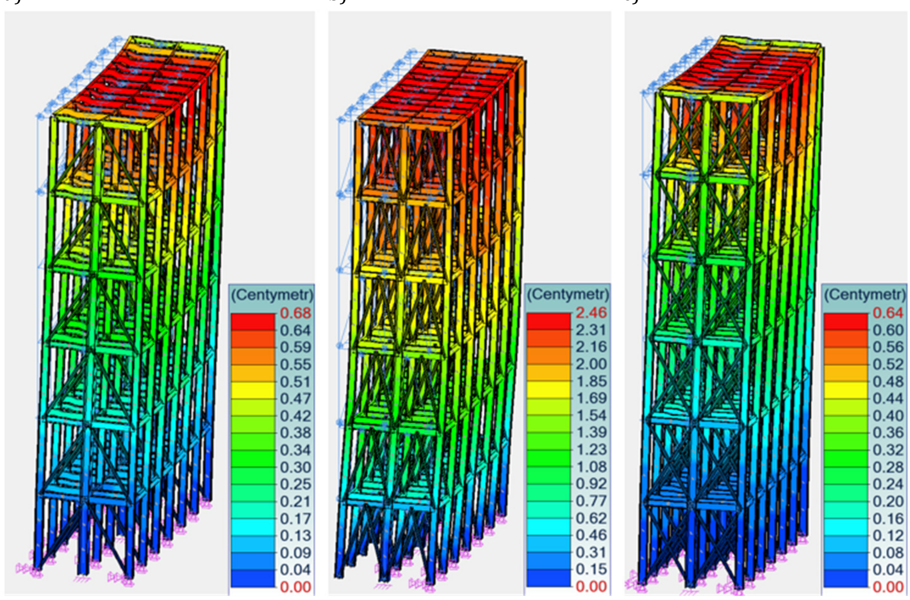

Fig. 2. Displacements in the structure obtained after adopting variants: a) type A, b) type M, c) type XX (own materials, using the Advance Design program)

The results in numerical form were collected and presented in Table 1.

Table 1
Maximum displacement of structure in three variants of supporting structure

Variant	Displacement Δx [mm]
Type A	6.80
Type M	24.60
Type XX	6.40

The determined support reactions for the supporting structure variants are presented in Figure 3.

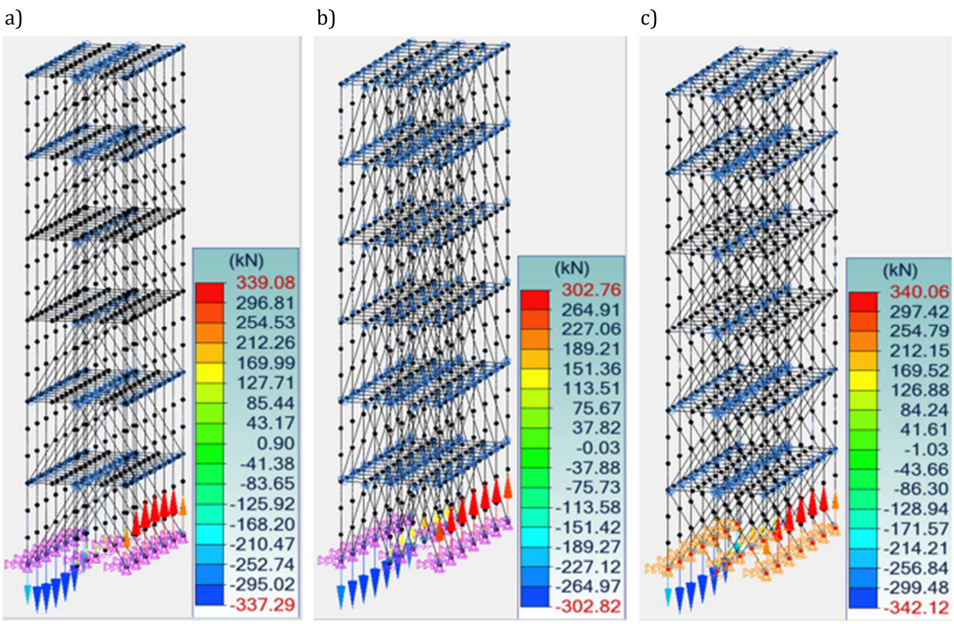

Fig. 3. Support reactions obtained after adopting variants: a) type A, b) type M, c) type XX (own materials, using the Advance Design program)

The response values were collected and presented in Table 2.

Table 2
Support reactions in three variants of supporting structure

Variant	Reaction R_{max} [kN]	Reaction R_{min} [kN]
Type A	339.08	–337.29
Type M	302.76	–302.82
Type XX	340.06	–342.12

The system selection was performed using formula (1). The comparison results are attached in Table 3.

Table 3
Support reactions in three variants of supporting structure

Variant	Displacement Δx [mm]	Reaction R [kN]	Criteria K [%]
Type A	6.80	339.08	2.01
Type M	24.60	302.82	8.12
Type XX	6.40	342.12	1.87

The most solution from variant No. 3 of type XX is shown in Figure 4.

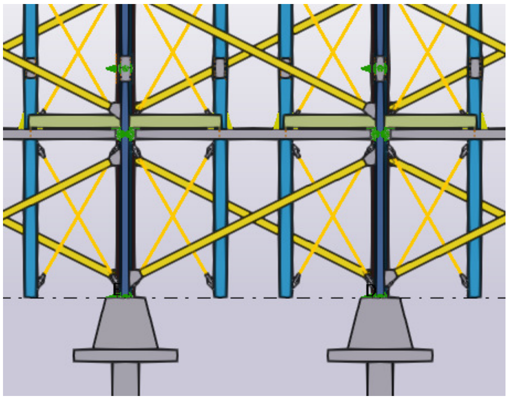

Fig. 4. Variant accepted for further work in the BIM model type XX (own materials, using the Blender program)

Based on the proposed criterion, it was shown that solution X is the most advantageous from the point of view of the structure's operation. The conclusions were formulated in the next chapter.

4. Conclusions

Based on the structure model, three variants of support structure systems were analyzed, which resulted in the selection of the location and orientation of the bracings for the purpose specified at the beginning of the article. As a result of modeling the systems, results were obtained for three variants of the structure. Differences in the values of both the displacements of the main structure elements and the reactions. Based on them and on the adopted criteria, it was shown that variant no. 3 obtained the lowest displacement to reaction ratio at the support points. The programs used in the project were carefully selected to ensure maximum compatibility between different design platforms. The key element was the possibility of easy data exchange between different tools without losing information. The exchange of digital models took place mainly using the IFC (Industry Foundation Classes) format, which is a widely used open standard enabling problem-free data exchange between different BIM software.

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Analiza statyczna konstrukcji nośnej regałów hal stalowych z wykorzystaniem modelu BIM

STRESZCZENIE:
Przedstawiono analizę statyczno-wytrzymałościową trzech wariantów konstrukcji wsporczej regałów hali magazynowej z wykorzystaniem modelowania BIM. Na podstawie modelu konstrukcji przyjęto trzy warianty, których schematy statyczne przedstawiono w pracy i poddano takim samym obciążeniom. Zaproponowano kryterium porównawcze, na podstawie którego dobrano wariant najbardziej korzystny z punktu widzenia pracy konstrukcji. Wymiana informacji modelu BIM odbywała się z wykorzystaniem formatu IFC. W pracy przedstawiono analizę wyników oraz wnioski.

SŁOWA KLUCZOWE:
model BIM; format IFC; konstrukcja stalowa; analiza statyczno-wytrzymałościowa